

Real-Time Course of Action Analysis

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Abstract

The military planning process, which involves a series of complex decisions in an uncertain environment, is highly manpower intensive and is carried out continuously throughout a campaign. Plans and strategies, which result in courses of action (COAs), are evaluated to determine the necessary steps to meet the overall strategic objectives. Currently, COAs are evaluated by two techniques. One technique involves teams of individuals playing both sides of a campaign, while trying to predict the outcome based on each others actions. This technique is manpower intensive, and cannot be maintained at the speed of current operations. The second technique involves automated wargaming technologies. Automated techniques are faster; however, they are performed against a scripted adversary and focus on attrition based modeling. They are incapable of assessing effects and their contribution to the overall mission objectives, which is inherent in effects based operations (EBO). The focus of this research is to develop technologies to assist decision makers in assessing friendly effects based COAs against an operational-level adversarial environment, faster than real-time. This paper will describe a demonstration test bed, and the associated research activities in support of real-time COA analysis. Initial demonstration results of several of the technologies will also be discussed.

Keywords: effects based operations; wargaming; scenario generation; center of gravity; course of action; adversary modeling; measure of effectiveness; measure of performance

1. Introduction

The military planning process depends upon analysis systems to anticipate and respond in real-time to a dynamically changing battlespace with counteractions. Complex technical challenges exist in developing automated processes to derive hypotheses about future alternatives for mission scenarios. The military conducts combat operations in the presence of uncertainty and the alternatives that might emerge. It is virtually impossible to identify or predict the specific details of what might transpire. Current generation wargaming technologies typically execute a pre-scripted sequence of events for an adversary, independent of the opposing force actions. A significant research challenge for wargaming is predicting and assessing how friendly actions result in adversary behavioral outcomes, and how those behavioral outcomes impact the adversary commander's decisions and future actions. The focus of this research is to develop technologies to assist decision makers in assessing friendly COAs against an operational-level adversarial environment. Utilizing high performance computing (HPC) technology, it is possible to dynamically execute multiple simulations concurrently to evaluate COAs for critical elements

related to execution and timing as well as overall effectiveness against a range of adversarial, or enemy COAs (eCOA) [1]. Conventional wargames are also insufficient when it comes to evaluating modern campaign approaches. They focus on traditional attrition based force-on-force modeling, whereas modern campaign strategies employ and evaluate a mixture of kinetic and non-kinetic operations. The Air Force is pursuing EBO as one such campaign approach [2]. EBO is an approach to planning, executing and assessing military operations that focuses on obtaining a desired strategic outcome or “effect” on the adversary instead of merely attacking targets or simply dealing with objectives. For wargames to be effective, they must allow users to evaluate multiple ways to accomplish the same goal with a combination of direct, indirect, complex, cumulative, and cascading effects. The overarching objective of this research activity has been to address the challenges of simulating EBO COAs in the presence of a dynamic adversarial environment, faster than real-time. Such a system will allow planners to evaluate the effectiveness of today’s alternative decisions and plans in tomorrow’s battlefield.

2. Research Program

The current development activities include multiple research components: a simulation test bed, a scalable, flexible simulation framework; automated scenario generation techniques with dynamic update; intelligent adversarial behavior modeling; effects based/attrition based behavior modeling; and real-time analysis technology for comparing and grading effectiveness of alternative simulations. The architecture for the research program is depicted in Figure 1. The force structure simulation (FSS) test bed was developed in-house to provide a capability to demonstrate the associated technologies necessary for performing parallel COA simulations faster than real-time. The simulation framework will provide the foundation for rapid decision branch COA analysis [3]. Techniques to be able to evaluate multiple parallel COA simulations, as well as multiple branches, within a single COA are being developed. Automated scenario generation techniques will enable the dynamic creation of simulation input files to support the concept of multiple parallel COA simulations [4]. Research on techniques to model adversarial behaviors will provide a simulation capability to anticipate potential adversarial actions for dynamic adversary COA analysis. A generic modeling methodology was developed in-house to implement EBO concepts within virtually any modern wargame simulator. The generic EBO model is capable of mimicking arbitrary EBO centers of gravity (COGs), which contain linkages and attributes of the target system. Techniques are also being investigated to define appropriate measures of effectiveness/measures of performance (MOEs/MOPs) for EBO COAs to help with the COA selection process.

This paper will describe the FSS test bed, and these associated research activities in support of real-time COA analysis. Since FSS is an in-house test bed, there is flexibility to modify the simulation environment as necessary to evaluate and demonstrate ongoing research and development activities. FSS runs on the Synchronous Parallel Environment for Emulation and Discrete Event Simulation (SPEEDES) framework [5]. SPEEDES was chosen as the foundation for FSS because it helps exploit available high performance computational resources and provides much needed functionality. SPEEDES distributes and coordinates simulations across multiple central processing units of various HPC architectures, including workstations, clusters, or combinations of architectures.

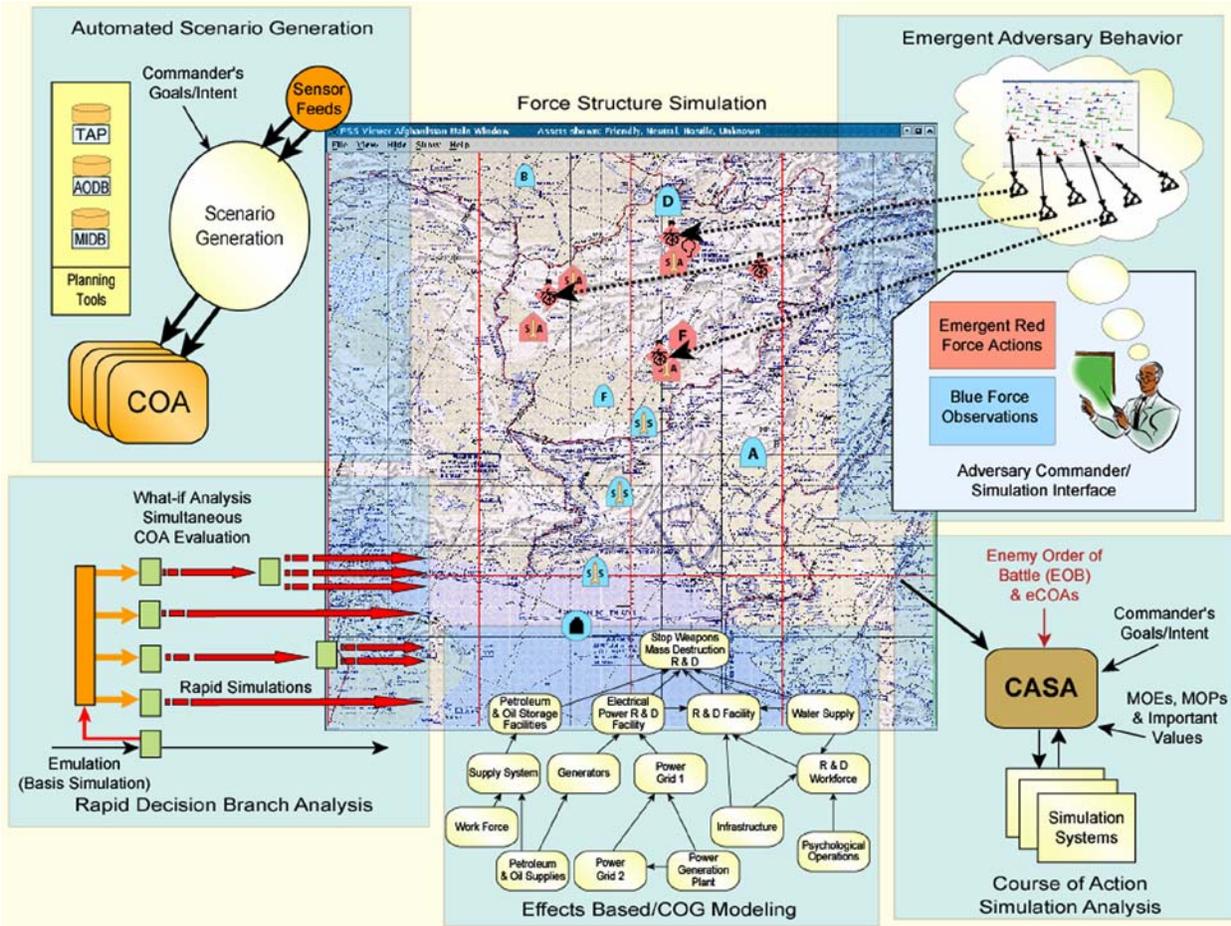


Figure 1. Real-Time Decision Support Architecture

3. Force Structure Simulation

The foundation for these research and development activities is an in-house force structure simulation (FSS) research test bed. FSS is a simulation test bed for development and integration of various supporting technologies relating to COA/eCOA comparison. This in-house test bed provides a means by which researchers can modify the simulation environment to support the implementation and prototyping of a variety of related research activities.

A range of widely used wargaming frameworks were examined before deciding to employ the SPEEDES framework. SPEEDES is a discrete event driven simulation with conservative and optimistic schemes of operation. All of the communications employed by SPEEDES are standard, architecture independent operations which enable the simulation to compile and run on a variety of HPC platforms. The framework supports C++ class structures. SPEEDES has been successfully used as the discrete event simulation framework by a number of wargaming environments.

Currently, FSS assets include aircraft, missiles (such as cruise missiles and theater ballistic missiles), surface to air missile launchers, Battle Groups, airports, factories, bunkers and command posts. The simulation is controlled by two parameter files. One parameter file

includes details of all of the assets and their properties; which include sensor range, initial location, alliance and status. The other parameter file details the missions that mobile assets will perform during the simulation, including routes, speeds, and targets.

4. Rapid Decision Branch Analysis

The simulation framework must also provide the foundation for rapid decision branch COA analysis. Research is being conducted to develop techniques to expand the capability of SPEEDES to evaluate multiple parallel COA simulations, as well as multiple branches, within a single COA. The basic concept is depicted in the lower left of Figure 1. This framework will also provide the capability to input current intelligence, surveillance, and reconnaissance (ISR) reports into a simulation toolset, allowing military planners to rapidly peer into the future at any given moment. Planners are then permitted to derive hypotheses about future alternatives. Notionally, an initial emulation--or basis simulation--could be running in the real-time environment. At critical decision points, the system will clone the simulation and the clone will rapidly execute into the future to evaluate possible outcomes of multiple COAs or decision branches. The cloned simulations leverage the HPC environment by dynamically utilizing free resources for faster than real-time evaluation. By running multiple parallel simulations simultaneously, the maximum computing power can be applied to the problem at hand.

The key to applying simulation technology in real-time is to maintain a simulated “mirror image” of the real world situation at all times. This simulated version of the real world can be used as the starting point for evaluating COAs and for simulating into the future to help predict what might happen. This simulated mirror image is referred to as the emulation. The emulation is a parallel simulation running at wall-clock (i.e. real-time) speed that is continually fed ISR reports so that it reflects the state of the battlespace to the extent known. Assuming that the emulation is run continuously on a defined number of processors of an HPC; the remaining processors will be available to run COA evaluations or predictive simulations. For example, if the HPC has 256 CPUs and the emulation occupies 8 CPUs, the remaining 248 CPUs will be available for performing COA assessments.

The approach to creating copies of the emulation for alternative COA analysis is referred to as cloning. Cloning a simulation means creating a running copy of the simulation, preferably on a separate group of “free” CPUs (i.e. processors with little or no workload). For example, if a simulation is running on CPUs 1-8 on a 128-CPU machine, a clone could be created and copied onto CPUs 9-16. The clone will be an exact duplicate of the original and will produce identical results as the original. By cloning the emulation, inserting new COA defining information, and allowing it to run as fast as possible, military analysts can get a glimpse into the possible future, faster than real-time.

This simulation framework provides the foundation for faster than real-time parallel COA simulations. COA analysis is the process of performing “what if” analysis of actions and reactions designed to visualize the flow of the battle and evaluate each friendly COA. Utilizing the developed methodology, along with performing “what if” analysis in an HPC environment, affords the opportunity to evaluate friendly COAs against a range of eCOAs. This range of adversarial COAs goes well beyond the “most likely” and “most dangerous” COAs, which are

evaluated in today's current environment [6]. It will encompass a dynamic adversary that responds in an intelligent manner based on friendly actions and adversary models. This will be further discussed in Section 6. A simple example will demonstrate the value of the HPC simulation framework for performing multiple COA evaluations, faster than real-time.

Consider an example where an analyst would like to evaluate 2 friendly COAs against a range of eCOAs. Assume the HPC resource supporting this evaluation has 64 CPUs and the emulation will utilize 4 CPUs. The analyst would be able to perform 15 parallel COA evaluations, assuming each simulation clone requires the exact same number of CPUs as the emulation, see Figure 2. Each arrow in the Figure represents a distinct COA/eCOA analysis. In this example, 8 distinct eCOAs are being evaluated against friendly COA#1 and 7 distinct eCOAs are being evaluated against friendly COA#2. The decision points represent an adversary's reaction to a friendly action. Note, in this example, 3 decision points are being evaluated for each adversary COA. Applying significantly more HPC resources will allow for more decision points to be analyzed. As one can imagine, there is a range of decisions that must be evaluated after each action/reaction within COA analysis.

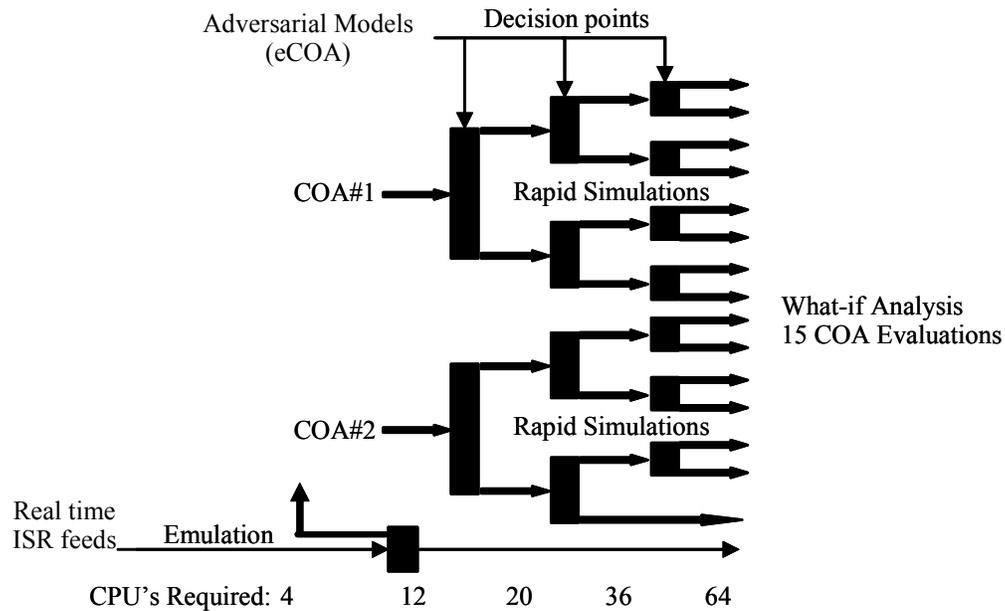


Figure 2. Simulation Cloning Example

To date, the mechanism for cloning a running simulation has been developed and demonstrated. Tests were performed to ensure that the cloned simulation ran identically to the parent from initial time to the simulation end time. After this was verified, the cloning mechanism was tested by varying the number of nodes and the memory configuration. Although the software is still in a rough state and requires more testing and generalization, this marked a significant milestone in progress towards multiple parallel COA simulations.

5. Automated Scenario Generation

A scenario describes the configuration parameters for running a specific simulation. These parameters specify the initial positions and quantities of assets, command structure, COG model, and the detailed missions to be exercised during each simulation run. These parameters must be supplied for friendly, coalition, and hostile forces. Scenario parameters are read from configuration files when the simulation begins. Sources of this information for scenarios vary, and can include proprietary database structures, mission plans, environmental constraints, and analysis reports. Current techniques for scenario generation are extremely labor intensive, often requiring manual adjustments to data from numerous sources to support increasingly complex simulations. The process of generating the required scenario files is manual and requires a person or persons to collect the requisite data from all of these disparate sources and assemble them together into a coherent simulation scenario. This laborious and error prone process presents a significant impediment to the research goal of rapidly assessing multiple COAs.

To meet the challenges of future mission planning requirements, a capability is required to be able to generate and assess tens or even hundreds of complete COA scenarios in a matter of minutes or hours. Clearly, automated approaches to rapid scenario generation are necessary to enable this critically needed capability. To address these challenges, research is being pursued in automatic scenario generation approaches and technologies that hold promise. The current efforts are focused on incorporating these approaches and technologies into an automated scenario generation toolset. The scenario generation toolset approach centers on a robust data model and the capability to tie mission-planning tools and data resources directly to an open COA analysis framework supporting a number of simulation tools.

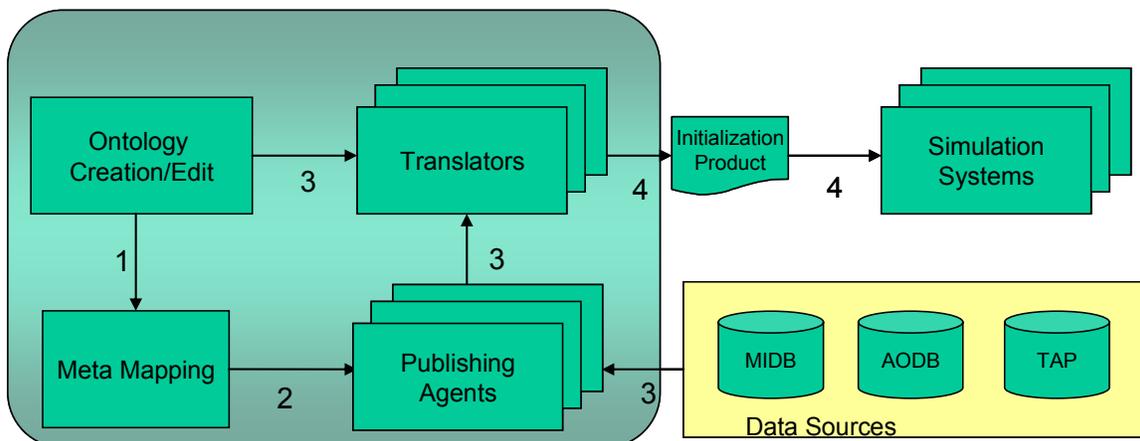


Figure 3. Scenario Generation Toolset Architecture.

Figure 3 illustrates the key components of the scenario generation toolset. One of the core technologies employed by the toolset is a web ontology language (OWL) that defines all of the requisite data needed for scenario generation and the relationships between these data. This model can be populated from the various data sources to create instances of data sets necessary for specifying scenarios. Since the data is captured in a semantic form (OWL), it can be reasoned over and analyzed for completeness and correctness. Missing elements can be detected and the user can augment the data set as needed. Automatic translation technology (Extensible

Stylesheet Language Transformation or XSLT, etc.) can then be employed to generate the scenario configuration files in the expected format for the simulator. At the time of this publication the toolset supports two simulator configuration file formats: the XML files used to configure the FSS, and the simulation control files used by the Extended Air Defense Simulation (EADSIM).

6. Emergent Adversary Behavior

In the current world environment, the rapidly changing dynamics of adversarial operations are increasing the difficulty for military analysts and planners to accurately predict potential actions. As an integral part of the planning process analysts need to be able to assess planning strategies against the range of potential adversarial actions. When the first decision in a given COA is implemented, subsequent decisions must be evaluated based on the new state of the world. This sequential action/reaction analysis concept requires predictive adversary models and these models are vital in assessing planned military decisions. For COA/eCOA analysis tools to be of greater use to military analysts and planners, they must incorporate models of adversarial behaviors that accurately predict potential adversarial actions. Conventional wargaming simulations typically execute a pre-scripted sequence of events for an adversary, independent of the opposing force actions. Traditionally, friendly COAs are wargamed against the “most likely” and “most dangerous” adversary COAs. A significant research challenge for wargaming is predicting and assessing how friendly actions result in adversary behavioral outcomes, and how those behavioral outcomes impact the adversary commander’s decisions and future actions.

The feasibility of utilizing an adversarial tool as a core element within a predictive simulation to establish emergent adversarial behavior are being investigated. Emergent behavior refers to intelligent dynamic adversarial actions generated at the operational level in response to the execution of the friendly force within the simulation. Multiple adversarial models with varying belief systems would be capable of automatically posing different actions and counteractions. The desire is to use intelligent adversary models to generate alternative futures in performing COA analysis. A significant amount of uncertainty accompanies any adversarial modeling capability. This uncertainty encompasses the process of decision making in a dynamic situation. Typically, models are abstractly created to reflect the adversary’s beliefs, goals, and intentions; all of which are based on friendly interpretation of the adversary. The uncertainty of this adversarial decision process makes it necessary to evaluate friendly COAs against a range of eCOAs. Also, based on analysts’ interpretations of the adversary, numerous reactions are possible in response to a friendly action. The capturing of these action/reaction dynamics is essential to the future of the COA analysis process. By simulating numerous COAs prior to and during engagement, it may be possible to estimate outcomes of adversary actions immediately after they are accomplished within an operational situation. This will allow decision makers to better respond to a dynamic and volatile adversary during execution, with counter actions.

To date, two techniques have been evaluated for dynamic emergent adversary behavior. One technique is based on the work presented in [1] and further discussed in [7]. In this approach, an inferencing system framework is utilized to infer hypothesis from which dynamic behavior is generated. The inferencing system is based on Bayesian belief networks, and captures the overall behavior of the adversary in terms of the following attributes: their general beliefs (about

themselves as well as the friendly force), perceptions, biases, and desired end-states. The adversary modeling system inputs observables from a simulation system and infers, in order of likelihood, the adversary goals and intents. From these goals and intents, adversary behavior and resultant actions are calculated. These resultant actions (eCOAs) are then input to the simulation system and executed by the adversary force.

The second approach to emergent adversary behavior utilizes hierarchical planning and ruled-based techniques. The adversary models will be based on objectives, actions, predicates and behaviors; and include aspects of cultural and extra-cognitive factors. These attributes will be captured by a model execution engine. This execution engine, which will be integrated with simulation, will be responsible for dynamically determining what actions will be taken by the adversary based on the adversary model and the current state of the simulated world.

In both approaches, adversary actions can be ranked in order of likelihood to occur. By applying HPC technology and the framework discussed in Section 4, it will be possible to evaluate the most likely adversary actions in parallel, instead of a single decision. These adversary modeling techniques have been successfully interfaced with FSS. The resultant proof of concept demonstrations showed that it is possible to dynamically execute the adversary force within a simulation. Both techniques are viable alternatives and demonstrate that eCOAs do not have to be pre-scripted. While these approaches were successfully implemented in a proof of concept demonstration, and are continuing to be pursued, they are not the only viable approaches to dynamic adversary modeling. This is a significant research challenge that will continue to be pursued into the future.

7. Effects Based/COG Modeling

Conventional wargames are inadequate when it comes to simulating modern campaign approaches. They focus on traditional attrition based force-on-force modeling, whereas modern campaign strategies employ a mixture of kinetic and non-kinetic operations. The Air Force is pursuing effects based operations as one such campaign approach. EBO is an approach to planning, executing, and assessing military operations that focuses on the effects produced from military activities, as opposed to the direct result of attacking targets [8]. For wargame simulations to be effective in an effects based arena, they must allow users to evaluate multiple ways to accomplish the same goal with a combination of direct, indirect and cascading events (actions).

To achieve this objective, an abstract modeling methodology was developed for the inclusion of EBO concepts into virtually any event driven wargame simulator [9]. This methodology produced a generic EBO model that is capable of mimicking arbitrary EBO COGs, which contain linkages and attributes of the target systems.

When planning EBO campaigns, military strategists rely on COG models, as the interdependencies are critical when utilizing a combination of direct, indirect, complex and cascading effects to accomplish military objectives. The EBO COG modeling methodology also uses the COG models to generate the dependency model. It extends the nodes of the COG model with critical EBO information that will enhance the simulation. Some of the information that is

gained by the extension is: delay times, recovery times, complex effects, and probability of effect.

The COG modeling methodology provides the framework necessary for simulating EBO concepts. One of the key EBO concepts is the cascading event. This simulation event represents the cascading nature of effects, which occur when a direct effect “ripples through an enemy target system, often influencing other target systems as well” [10], resulting in an indirect effect or outcome. In the wargame, this occurs when one simulation object is influenced by another simulation object that it relies upon. For example, if a factory is dependent on a power plant to operate, then an event that causes the power plant to be disabled will cascade to the factory causing the factory to be affected and possibly shutdown. A second essential EBO concept is the complex effect. This type of effect reflects the cumulative nature of effects. As described in [10], “cumulative effects result from the aggregate of many direct or indirect effects”. For example, the production capability of a factory could be halted by destroying or disrupting numerous transfer stations and generators, which are necessary for the power plant to function. The ability to have simulation objects recover from both direct and indirect effects is also included in the EBO COG model. For instance, a factory can be affected by the loss of power caused by the destruction of a power line. The power line can be repaired (recover) in a given time, and cascades its recover event to the factory and any other simulation entity reliant upon this power line.

This EBO COG modeling capability is integrated into FSS, which transformed it from an attrition based simulator to one capable of simulating EBO. The process required the introduction of three new classes to FSS. Two classes were necessary to implement the modeling methodology; one class handled the logic and events, while the other was used to store the EBO COG information. With the introduction of effects based properties in FSS, came the need to be able to model abstract concepts. A new class was created for the simulation to represent the abstract concepts. This abstract simulation object represents an entity that is comprised of many locations, but could be modeled as one (e.g. Work Force). Further documentation of the integration process can be found in [11].

To verify that the EBO modeling capability was successfully integrated within the FSS test bed, COA simulations of a simple, fictional scenario were executed. A test scenario was developed that encompassed a simple COG model, which included complex and cascading node interdependencies. For comparison purposes, two simulations were executed on the same scenario; one incorporated the COG model, resulting in an EBO simulation and the other without the COG model, resulting in a conventional force-on-force simulation.

The operational objective of the simple scenario was to disable Airport 1 by disabling the two Air Defense Commanders, shown in Figure 4. The Blue force will launch four aircraft from a Blue battle group to engage the Red bunker and the three power plants. The Red commander (Air Defense Commander 2) will deploy a Surface to Air Missile (SAM) asset, to engage the Blue aircraft, unless complex and cascading effects disable the Red commander.

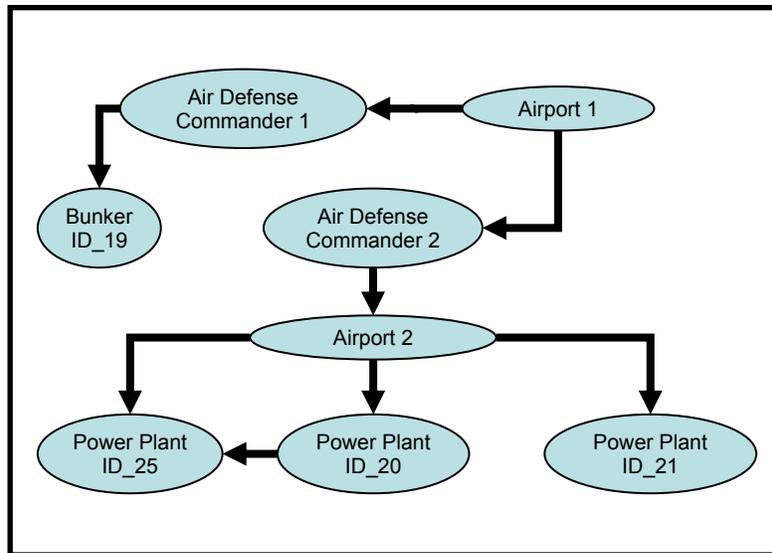


Figure 4. Center Of Gravity Model

Figure 4 illustrates the COG model for this simple example, which specifies assets and commanders. Air Defense Commander 2 depends on Airport 2, which in turn depends on the three power plants. Airport 1 depends on the two Red commanders, Air Defense Commander 1 and Air Defense Commander 2. Air Defense Commander 1 is resident in Bunker ID_19 and is dependent on that bunker.

The time line of events for the simulation can be seen in Figure 5, where the events associated with the COG model are highlighted. In the scenario, aircraft are launched; they engage the bunker and the three power plants and return to the battle group. When simulated without a COG model, the bunker and power plants are destroyed, the SAM is deployed and engages the aircraft, two of which are destroyed. The other two aircraft return safely to the battle group.

When simulated with a COG model employed, the destruction of the bunker causes a cascading event to disable Air Defense Commander 1. The destruction of power plant 25 cascades to disable power plant 20. The destruction of power plant 21, cascades to disable Airport 2 and its commander, and results in Airport 1 being disabled. Because Air Defense Commander 2 was disabled, the SAM was not activated, and all aircraft survive the mission. Furthermore, because the COG model includes recovery times for assets; the power plants, bunker, airports, and Red commanders recover prior to the completion of the simulation.

The integration of the EBO COG modeling methodology into the FSS test bed created the first practical wargame environment capable of simulating effects based operations. FSS supports indirect, cascading and complex effects, which are an essential characteristic of effects based operations. This capability enables next generation Concepts of Operations regarding EBO to be assessed and evaluated within a simulation environment in much faster than real-time.

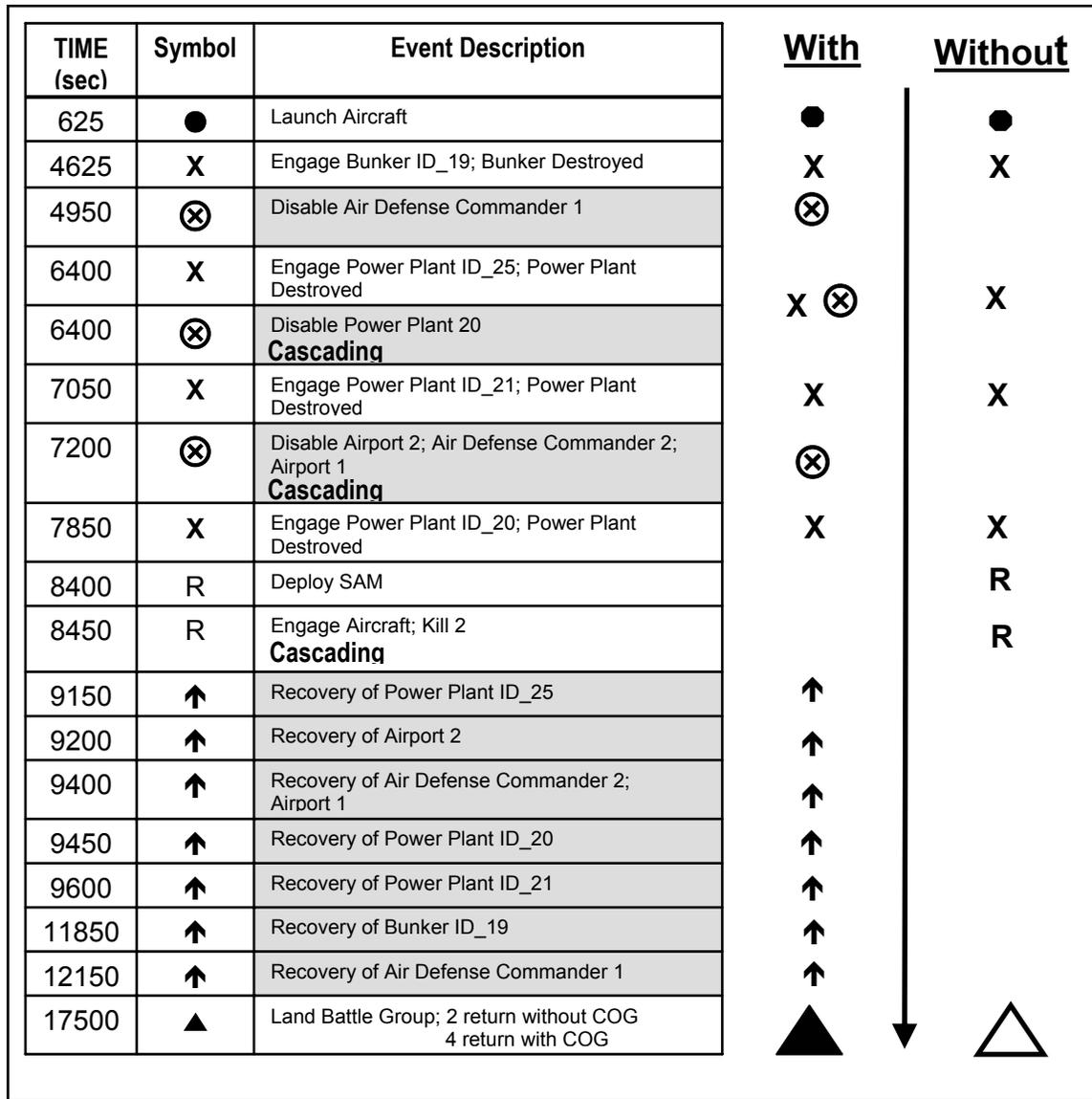


Figure 5. Time Line of Events in Simulation

8. Course of Action Simulation Analysis

Simulation of many scenarios for Blue against many scenarios for Red in an EBO environment poses questions regarding which simulation outcome most closely approaches the intent of the commander. Even in a strictly force-on-force attrition based simulation, the analysis ought to include measures that indicate the relative merit of particular targets and target sets. In an EBO environment, where the targets must map into target sets and centers of gravity, and where indirect consequences to direct actions may in fact be the desired effect, these measures and how to compare simulation results against these measures is problematic.

The Course of Action Simulation Analysis (CASA) effort is researching the underlying technology related to just such an analysis. Techniques are being investigated to define appropriate measures of effectiveness and measures of performance (MOE/MOP) for EBO

COAs. Once defined, analysts can use these metrics to rate and rank the relative merit of each COA evaluated through an operational-level wargaming simulation. The goal of the CASA effort is to identify a very low-level, fundamental, and common set of characteristics that, when aggregated, can be used to describe any MOE or MOP. Such an established set of characteristics would provide a direct means of comparison for disparate approaches that multiple COAs would unavoidably reflect. The analysis of the simulation results could eventually feed into the Joint Air Estimate Process for COA analysis, COA comparison and COA selection [12].

A data representation ontology and schema for a course of action have been developed, and a manual first attempt at a CASA process flow was delineated and exercised. This process flow began with commander's intent captured in an EBO strategy development tool. Associated objectives, tasks, centers of gravity and measures were then captured in an XML instance document. Simulations were performed using the attrition based EADSIM wargame, and the results were rolled up into a populated version of the instance document in consideration of the centers of gravity. A preliminary visualization technique of the results was accomplished. Visualization of results, when comparing many simulation results is crucial for providing commanders with insight into the strengths, weaknesses, and consequences of a particular COA. This research is discussed more fully in reference [13].

9. Summary

This paper describes the current research activities towards the realization of a next generation COA analysis capability. A major goal of the FSS concept is to develop a test bed to demonstrate associated technologies necessary for performing parallel COA/eCOA simulations, faster than real-time. Developing a complete simulation tool for the end-user community is beyond the research scope. The intent is to demonstrate to user communities the exciting potential for a COA/eCOA technology that will provide increased awareness and insight for decision makers before and during operational situations. To date, several technologies have been demonstrated related to the research effort. The initial demonstration, the FSS test bed, was to prove the concept of multiple parallel COA simulations. Since the initial FSS demonstration, the following capabilities have also been demonstrated: simulation cloning, automated scenario generation, EBO simulation modeling, dynamic adversary modeling and COA simulation analysis. A longer-term, more ambitious goal is to combine all of the concepts described in this paper into a single demonstration.

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